Iron in Montana's Groundwater: How to Recognized and Manage the Problem

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by

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IRON AND IRON-BACTERIA IN MONTANA GROUNDWATER

Report No. 160

by

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1. INTRODUCTION

This report describes results of an informational project to identify and address iron-related groundwater problems in Montana.

Information included in this report has been condensed from:

- a literature review of iron bacteria and iron water-quality problems

- a computerized data search for iron water quality problems in municipal and domestic wells in Montana

- a survey of currently-available solutions to these problems

The help of the following individuals is recognized:

- John Arrigo of the State Department of Health and Environmental Sciences, for case histories of iron bacteria occurrence from throughout the state

- municipal officials in Wolf Point (Charles Worley), Plentywood (Chuck Devaney), and Sidney (Greg Anderson), for sharing information regarding their water systems and their experience with iron problems

- technical representatives of water-conditioning equipment suppliers, for providing details on engineering and capabilities of their equipment

- John Jarvie of the Department of Health and Environmental Sciences, for sharing data from the DHES water quality database

No conclusions are drawn in this report as to the effectiveness or performance of any of the water-treatment equipment described, nor is any endorsement of individual products expressed or implied. Specific products or brands mentioned are included as examples of currently (1987) available equipment for treatment of iron-rich water.

2. Occurrence of Iron in Montana Groundwater

Throughout most of Montana, local residents have access to potable groundwater supplies within 1000 feet of the surface. The quality of this water is highly variable from place to place; some is highly mineralized in comparison to currently-used groundwater in other states. However, because groundwater is often the only available source, local residents as a rule adapt to many aspects of its water chemistry, including high levels of hardness, total dissolved solids, sodium, and sulfate. One constituent is a widespread exception to this rule: iron.

The symptoms of an iron-rich groundwater supply are easily visible in Eastern Montana households and towns. In addition to fouling and discoloring clothes, plumbing fixtures, dishwashers, house siding, and dishes, solid iron deposits -- iron hydroxide, or "yellow boy" -- can, over a period of years, plug off house plumbing and even water wells themselves. Also, iron bacterial accumulations may occur in a large percentage of wells with elevated iron concentrations in eastern and central Montana. These bacteria do not cause high iron concentrations, but thrive in iron-rich groundwater and cause plugging, encrustation, and corrosion problems in wells, aggravating an already serious problem. Montana landowners are frequently faced with iron bacterial infestations which are usually not recognized or treated until it is too late.

2.1 Geochemistry of Iron and Manganese in Groundwater

Iron is a common constituent of many different types of rocks and sediments, some of which are aquifers. Groundwater tends to develop chemical characteristics which reflect the chemical composition of the aquifer through which it passes; this is especially true if the aquifer is rich in easily-soluble salts or minerals. Formations in Montana which are especially iron-rich include: sandstone of Cretaceous (Eagle, Judith River, and Kootenai formations) and Tertiary (Fort Union Formation) age; many volcanic deposits, particularly in the mountainous portions of the state; and alluvial and glacial sediments derived from the iron-rich bedrock formations mentioned above.

A source of iron is a prerequisite, but not the only requirement for iron in groundwater to reach high levels. The chemical environment within the aquifer strongly influences iron concentrations. The stability fields and solubility of iron are strongly influenced by the oxidation potential (called "Eh", expressed in units of electrical potential) and pH of the water. The common mineral species which control iron solubility include iron carbonate (siderite), iron sulfide (greigite, pyrite), and iron oxide or hydroxide (hematite, amorphous iron hydroxide). Most groundwater is impoverished in oxygen (that is, it exhibits low Eh) and of near-neutral pH. Under these conditions and in the presence of soluble iron minerals, dissolved ferrous (reduced) iron concentrations can rise to high values -- 5

milligrams per liter (mg/L), or parts per million (ppm), is not uncommon. For comparison, above about 0.3 mg/L (the recommended EPA secondary drinking water limit), water contains just enough iron to begin to cause fouling problems in normal use.

Iron at high concentrations entering a water well is in the reduced (ferrous) state, dissolved, colorless, and not visible to the eye. When water is pumped from a well -- into cisterns, sinks, toilets, lawn sprinklers, and laundries -- it enters an oxygen-rich environment very different from that within the aquifer, and the ferrous iron is rapidly converted to the ferric (oxidized) state. The solubility of ferric iron is extremely low (less than 0.01 mg/L) except under low pH conditions, and following oxidation it rapidly precipitates from solution as a fine, yellow- or red-brown hydroxide deposit. Water containing such ferric hydroxides in suspension is referred to as "red water" in the water-conditioning industry. In standing water, the precipitate will settle from suspension and accumulate at the bottom. The hydroxides have a high surface charge and can absorb and bond firmly to many materials, including porcelain, siding, etc. The precipitation process is normally fairly rapid, but is accelerated by addition of chemical oxidizing agents, such as chlorine or permanganate.

Manganese is a common trace metal often occurring in iron-rich minerals, such as biotite, hornblende, and amphiboles. Manganese oxides are common weathering products of these minerals. Manganese can occur in the reduced ($Mn2+$) form at near-neutral pH up to concentrations over 1 mg/L, at near-surface oxidation levels. At higher pH (above 8), it is oxidized to the $Mn4+$ ion, which will precipitate as manganic oxide. Manganese occurs at generally lower concentrations than iron, but will precipitate as an oxide with greater difficulty. The EPA secondary limit for manganese is 0.05 mg/L, due to aesthetic reasons as for iron. Manganese oxides form a black precipitate. Well water with high levels of iron will commonly also exhibit high levels of manganese. While iron commonly occurs in higher concentration, manganese is more difficult to remove by water treatment, due to the slower kinetics of oxidation from $Mn2+$ to $Mn4+$.

2.2 Extent of the Problem in Montana

2.2.1 Domestic Wells

A statistical analysis of domestic and stock wells in Montana was performed using water quality analytical data from the Montana Bureau of Mines and Geology (MBMG) Ground Water Information Center (GWIC). A dataset was abstracted from this database for all domestic and stock wells within the north and east townships of the state. This represents about 75% of the area of the Montana Great Plains. Other wells (research, municipal) were excluded from the dataset, because this information is less random in nature than the domestic and livestock well data. The area from which the sample was drawn contains a wide variety of both bedrock and unconsolidated

aquifers. A total of 1804 well water analyses was included in the dataset.

Whereas source aquifer for a groundwater supply is not the only variable affecting its iron concentrations, it is a significant one. Therefore, subsets for specific aquifers were created (Table 1). Elementary statistics (arithmetic and lognormal mean, standard deviation, median, range) were calculated for each aquifer subset. Also calculated were the percentage of wells in each subset exceeding (A) the secondary EPA limit of 0.3 mg/L, and (B) 1.0 mg/L, a concentration above which iron is high enough to cause moderate to severe fouling problems.

The sample distribution for each subset is similar in appearance to a bimodal lognormal distribution; the lower-concentration mode represents waters below the detection limit (for most analyses, <0.002 mg/L). Arithmetic means range from 0.39 to 1.65 mg/L; lognormal means range from 0.06 to 0.18 mg/L (Figure 1). The lognormal mean is depressed by the relatively large proportion of samples below detection.

The lognormal mean is approximately equal to the median for each distribution. The arithmetic mean is approximately equal to the median of samples with detectable iron concentrations. The arithmetic mean appears to be the best indicator of the severity of iron problems in iron-affected wells. The proportion of wells over the 0.3 mg/L EPA limit is an effective indicator of the incidence rate of wells with iron problems. Both these indicators are thought to be conservative because all samples in the dataset were analyzed for dissolved iron using a filtered and acidified sample, from which it is likely that some iron was oxidized, precipitated, and removed by filtration prior to analysis.

The results for percent of samples over 0.3 mg/L (a measure of frequency of wells with iron problems, or "incidence level") and for arithmetic mean concentration (a measure of how badly each well is affected by iron, or "severity level") within each subset are presented in Figure 2. There is reasonably good correspondence between the two except for the Judith River Formation subset, for which incidence level is low in comparison to its mean concentration.

Aquifers with the highest severity of iron problems include glacial aquifers (X=1.65 mg/L) and alluvial aquifers (X=0.99 mg/L). The Fort Union and Kootenai Formation aquifers have intermediate levels of severity, from X=0.7-0.9 mg/L, and incidence levels approaching those of the glacial aquifers. Other Cretaceous sandstone aquifers -- the Judith River and Eagle-Virgelle Formations --, Jurassic aquifers -- Morrison Fm., Swift Fm., and Ellis Group --, and Tertiary alluvial and terrace gravel aquifers have somewhat lower incidence and severity levels, but still have mean concentrations greater than 0.5 mg/L. The lowest concentration of iron occurs within Paleozoic aquifers -- including the Madison Group, Amsden

AQUIFER	GEOLOGICAL AGE	SAMPLE SIZE	MEANS		MEDIAN	LOW VALUE	HIGH VALUE	PER CENT EXCEEDING:	
			ARITHMETIC	LOGNORMAL				0.3 mg/L	1.0 mg/L
Alluvium	Holocene	211	0.99	0.13	0.11	<.002	20.1	31	19
Glacial Deposits	Pleistocene	86	1.65	0.16	0.14	<.0022	21.6	41	23
Terrace Gravels	Tertiary	439	0.53	0.06	0.06	<.002	15.5	25	15
Fort Union Fm	Tertiary	279	0.83	0.17	0.18	<.002	17.41	37	22
Fox Hills/ Hell Creek Fm	Upper Cretaceous	235	0.39	0.09	0.09	<.002	12.0	22	7
Judith River Fm	Upper Cretaceous	216	0.72	0.12	0.09	<.002	31.7	25	12
Eagle & Virgelle Fms.	Upper Cretaceous	63	0.53	0.09	0.10	<.01	14.6	27	11
Kootenai Fm	Lower Cretaceous	121	0.74	0.13	0.26	<.002	11.1	41	18
Morrison Fm., Swift Fm., Ellis Gp.	Jurassic	44	0.70	0.13	0.09	<.002	5.4	32	23
Madison Gp., Amsden Fm., Big Snowy Gp.	Paleozoic	40	0.32	0.04	0.02	<.002	3.61	12	10
All Aquifers		1804	0.70	0.10	0.11	<.002	31.7	29	15

Table 1. Statistical analysis of dissolved iron in domestic and stock water wells, north and east townships, Montana. Source: Ground Water Information Center, Montana Bureau of Mines and Geology.

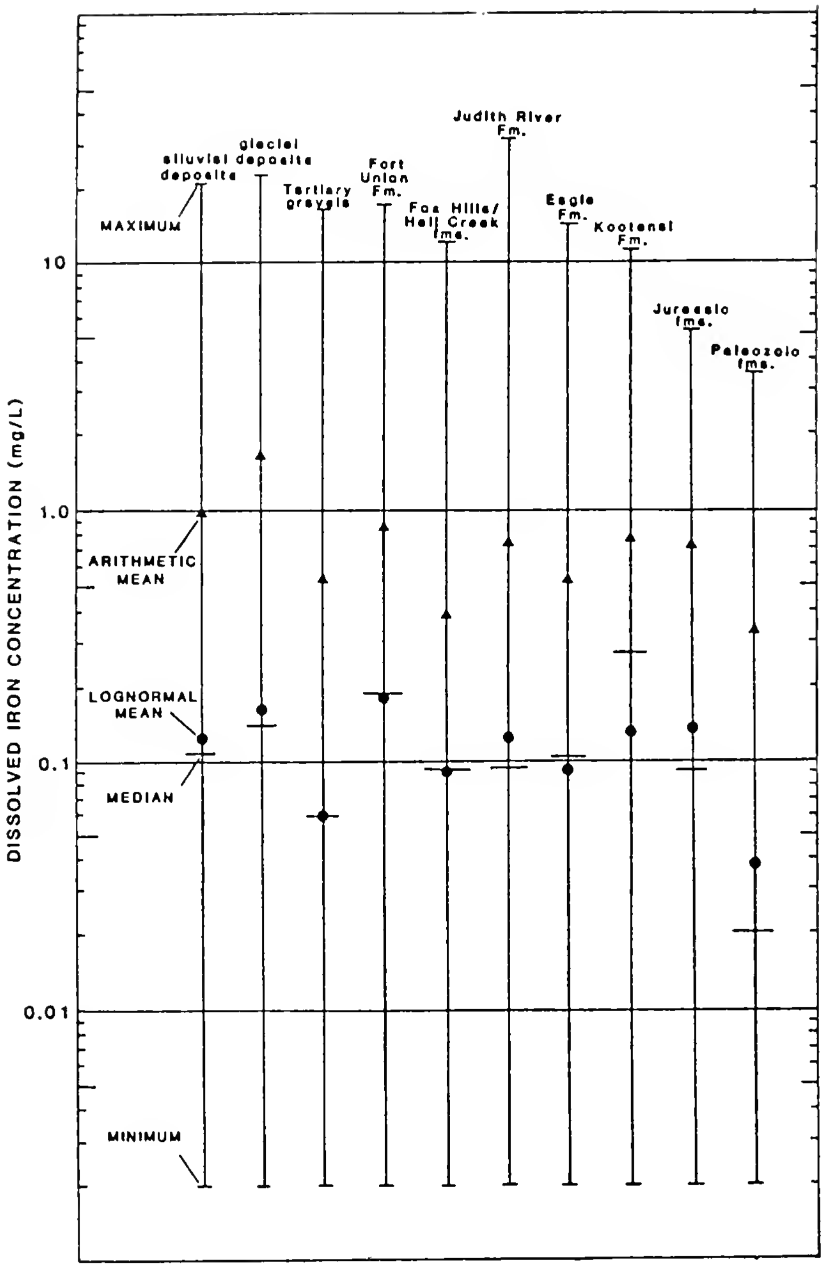

Figure 1. Bar plots of sample means (arithmetic and lognormal), medians, maxima, and minima for dissolved concentrations in domestic and stock water wells. Results are listed by producing aquifer.

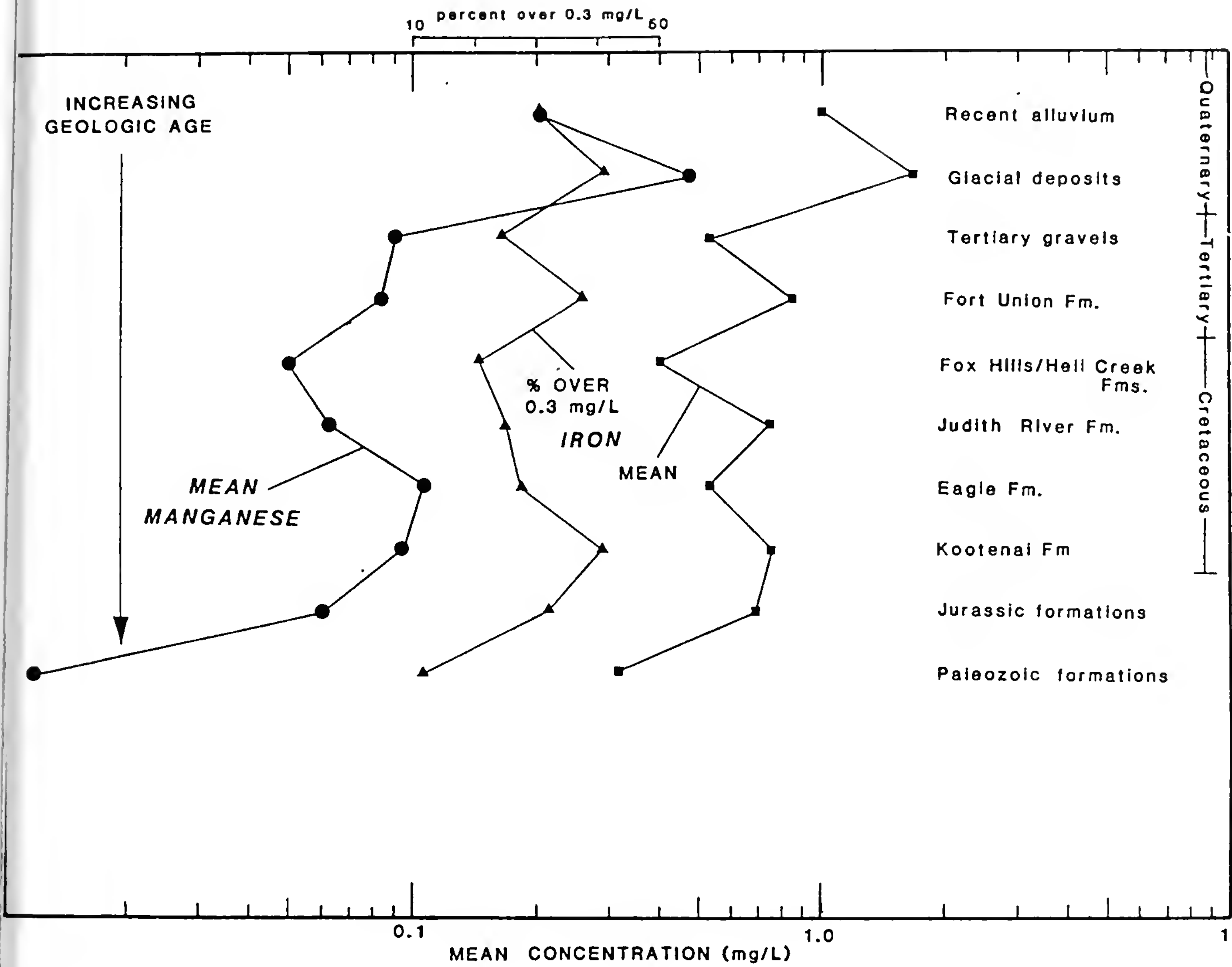

Figure 2. Arithmetic means of dissolved iron concentrations (squares); of dissolved manganese concentrations (circles), in mg/L; and of percent of samples with iron over 0.3 mg/L (triangles) for domestic and stock wells in different Montana aquifers. Aquifers are listed in order of increasing geologic age from top to bottom.

Formation, and Big Snowy Group --, with an arithmetic mean of 0.32 mg/L, and only 12% of samples over the 0.3 mg/L EPA limit. With minor exceptions, manganese concentrations follow the same trend as iron, but are about an order of magnitude lower.

These results should be interpreted cautiously as this analysis takes no account of critical geochemical environment factors such as Eh and pH. However, the dataset used is of sufficient size and the sample design sufficiently random that the results are thought to be significant. The relatively young and shallow alluvial and glacial aquifers are at highest risk of producing water with high iron. This agrees with the experience in southern Saskatchewan where locally up to 90% of wells carry high iron loads, dominantly in glacial aquifers (Cullimore and McCann, 1977). Somewhat less serious, but still above-average, iron fouling problems occur in water from the Fort Union and Kootenai formations, both aquifers of relatively good quality water in many areas of the state. The aquifers least prone to iron problems are the Paleozoic aquifers and the Fox Hills - Hell Creek aquifer, in which both incidence and severity exhibit low values.

Figure 3 is a map of the state upon which are plotted locations of all domestic and stock wells having iron in excess of 3 mg/L (large circles) and 0.3 mg/L (small circles). The problem is essentially statewide, with major areas of concentration in the northern and northeastern parts of the state.

DISSOLVED IRON IN MONTANA GROUNDWATER

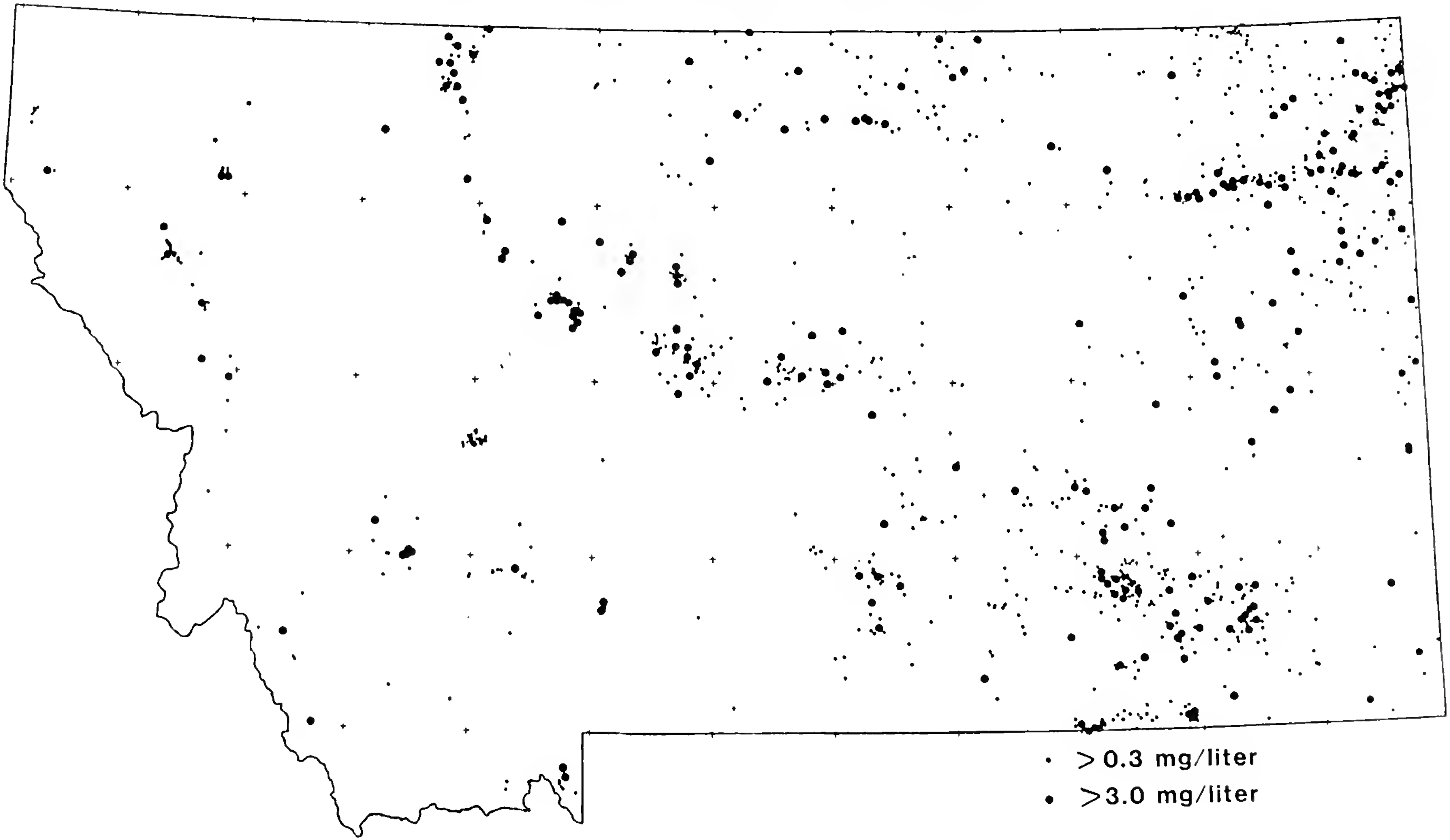

Figure 3. Dissolved iron concentrations in Montana groundwater. Large circles indicate samples with 3.0 mg/L or more iron; small circles have 0.3 mg/L iron or more, the EPA secondary limit. Source: Ground Water Information Center.

2.2.2 Municipal Wells

There are too few municipal supply analyses in the GWIC water-quality database for statistical analysis. The state Department of Health and Environmental Science (DHES) database includes samples collected approximately every three years from all municipal supplies (surface and groundwater). These samples are generally collected from points of use, such as taps in the town hall or bar, and are in most cases not specific with respect to source, well location, or other sampling details. Therefore, these "supply system" samples are difficult to ascribe to specific aquifers, and, in fact, in some cases are mixed ground- and surface-water samples. Information on sample handling (filtration, acidification) and well construction is limited.

Despite these limitations in sample information, a simple statistical summary is possible for water supplies in 142 towns with groundwater sources (Table 2). A total of 22 (15%) had iron in excess of its EPA secondary limit (0.30 mg/L), whereas 33 (23%) had manganese in excess of its EPA limit (0.05 mg/L). Arithmetic mean for iron in those systems exceeding the EPA limit is 3.04 mg/L, although most lie below 2.5 mg/L. Mean manganese in high-manganese systems is 0.45 mg/L, with most below that value. In most (15) of the high-iron systems manganese is also above the EPA limit. A list of towns with high iron and/or manganese concentrations is presented in Table 3. Towns noted with an asterisk are known to have some form of iron treatment system besides chlorination. Those marked with double asterisks have changed sources for their systems since the analytical data was collected. Similar to the domestic well data, these results are probably conservative, due to sample handling uncertainties.

Based on this crude evaluation, approximately 20% of all municipal supplies in the state have iron or manganese problems to some degree in their water supply, and fewer than 5% have resorted to treatment or to development of alternate supplies. In contrast, 52 North Dakota municipalities have iron removal facilities (North Dakota Department of Health, personal communication, 1986), primarily of a gravity or pressure filtration design.

Table 2. Statistical summary of iron and manganese concentrations in municipal water supplies using groundwater in Montana. Source: Montana Department of Health and Environmental Sciences.

Constituent	systems over EPA limit		Concentration (mg/L) systems over EPA limit		all systems	
	number	percent	mean	high	mean	median
Iron	22	15%	3.04	26.1	0.56	0.05
Manganese	33	23%	0.45	2.55	0.16	0.02

Total Sample size: 142 Systems

Table 3. List of Montana towns with high iron, manganese, or iron and manganese in public groundwater supplies. Source: Montana Department of Health and Environmental Sciences.

TOWN	IRON	MANGANESE
Antelope *	X	X
Ashland	X	X
Bainville **		X
Belt	X	
Big Sandy		X
Broadview	X	
Brockton		X
Browning		X
Cascade		X
Charlo		X
Culbertson **	X	
Dutton *	X	X
Fairview	X	X
Flaxville **	X	X
Frazer		X
Froid	X	X
Fromberg		X
Geraldine	X	
Geyser	X	X
Glasgow *	X	X
Grass Range *	X	X
Havre		X
Huntley		X
Joliet		X
Judith Gap	X	X
Medicine Lake	X	X
Nashua		X
Phillipsburg	X	
Poplar *	X	X
Roundup	X	X
Saco	X	X
Scobey	X	X
Sidney *	X	X
Stanford *	X	X
Sunburst	X	
Three Forks		X
Vaughn *	X	X
Wibaux	X	
Winnifred		X
Wolf Point *	X	X

* indicates system with some form of iron treatment
** indicates supply source currently not in use

3. Iron Removal in Montana Groundwater

3.1 Fundamental Concepts

Three basic approaches to treating ion-rich water are:

- to oxidize ferrous iron to ferric using either chemical or aeration techniques, followed by removal using gravity or pressure filtration

- to absorb ferrous iron onto an ion exchange resin, as in a conventional water softener

- to maintain ferrous iron in a soluble form using chemical additives (sequestering agents)

Most forms of iron treatment use variations of these approaches.

3.1.1 Oxidation/Filtration Techniques

Oxidation is accomplished by injection of oxidants ahead of the filtration cycle, followed by thorough mixing in pressure or settling tanks. Commonly used oxidants are either chemicals or air.

Chemical oxidants in common use are chlorine (as gas), sodium (or calcium) hypochlorite, and potassium permanganate. Potassium permanganate is used in systems with greensand filters because it also regenerates this material's ability to oxidize and absorb manganese. All these oxidants are capable of rapidly converting ferrous iron to ferric, and manganous manganese to manganic. However, oxidation of manganese is the slowest, most limiting step in the process, occurring very slowly below a pH of 8. Therefore, permanganate-greensand filter systems are frequently used to catalyze manganese removal.

Oxidation by aeration is accomplished using compressed air in pressure-filter systems or by using forced drafts in gravity-filter systems. Several newer systems utilize passive air intake systems, inducing an airstream into the water inlet flow using a venturi-like air inlet valve. Air-oxidation systems can be very effective for iron oxidation, but commonly have more difficulties with manganese, particularly at higher pH. Their main application is in waters with high iron only, although they may be capable of manganese removal up to about 0.5 mg/L. The pH may be adjusted, either by injection of alkaline solutions or by including alkaline materials such as carbonates in the filter media, to speed up manganese oxidation.

A very small number of large treatment systems use ozone (O_3) generated on-site for oxidation and disinfection. This is an effective but expensive process.

Filtration techniques are used in most cases to remove iron, although where raw water iron levels are high, a

sedimentation basin ahead of the filter is often used to avoid overloading the filter. A variety of filter media are used; however, all filtration techniques require periodic backwashing to remove solid iron precipitates. Frequency of backwashing is dependent on iron load, water demands, and filter bed capacity. Backwashing is automatically timed on more sophisticated systems. The volume of water required to backwash is several times the service flow rate of the system.

Filtration media are generally proprietary mixtures for which detailed specifications are not released by manufacturers. Popular components of these mixtures include: silica sand; activated charcoal; manganese greensand (glauconite) for use in permanganate systems; calcium carbonate, for use with water requiring pH adjustment; and crushed anthracite or other coal-based products. Filter mixtures must be uniformly sized to prevent segregation during backwashing and to resist plugging while still maximizing filter effectiveness.

One filtration technique introduces no air or chemicals to the system, but filters directly through granular coal-based material, such as "Birm ". This material strips oxygen dissolved in intake water, absorbing it as OH- and catalyzing oxidation. Iron-removal capacity is limited by surface area of the filter bed and by the supply of dissolved oxygen in the water. Because only shallow water-table aquifers have appreciable dissolved oxygen, direct filtration systems such as this can be ineffective for deep, oxygen-poor groundwater sources, particularly those with high iron concentrations.

3.1.2 Softening

Probably the most extensive technique in current use for residential-scale iron removal is ion exchange using a conventional water softener. Softeners utilize filter media called resins, formed of zeolite minerals. Zeolites are a family of hydrous aluminum silicate minerals with a variety of ion-exchange properties. Softeners are installed primarily to remove hardness, but will also remove small quantities of ferrous iron. No oxidation is required to remove ferrous iron up to 3-10 mg/L, according to some manufacturers' claims. In practice, there are limitations to a softener's effectiveness. Often some ferric iron will already be in the water when it reaches the softener; if fine enough, this iron will pass the softener. Ferric hydroxides which are filtered out can bind to and clog the filter resin, even after backwashing. Such fouling can damage the resin and reduce softener effectiveness. The degree of such fouling normally increases with iron concentration. Some suppliers of water conditioning equipment will not install softeners for removal of more than 1 to 2 mg/L iron.

3.1.3 Sequestration

One non-oxidative approach which has proven successful in mitigating iron problems is injection of polyphosphate solutions as sequestering, or complexing, agents. The large polyphosphate molecules effectively tie up the ferrous iron, keeping it dissolved and unoxidized for hours to days. Some products even claim effectiveness in re-dissolving ferric iron precipitates in the supply system. No iron is removed from the water, but the water remains clear and the iron in solution. Polyphosphate effectiveness may be measured in terms of how high a concentration it can keep in solution and for how long. These systems are in use in homes and municipalities nationwide, and can be an inexpensive solution.

There are some drawbacks to polyphosphate systems. Polyphosphate can be an effective nutrient for bacteria in the distribution system; thus for health reasons the Montana DHES specifies that chlorination be used in conjunction with polyphosphates in municipal systems. Also, the DHES maximum allowable phosphate concentration is 10 mg/L. Antisiphon devices and check valves must normally be used to prevent concentrated feed solution from entering the well inadvertently. Disposal of phosphate-rich drain water can be a contamination hazard where septic systems are in use adjacent to lakes or shallow water table aquifers.

3.2 Iron Treatment and Removal

Table 4 shows a list of a variety of iron-treatment equipment for either residential or municipal use. This list is not comprehensive, but gives an indication of the range of product types and applications commercially available today (1987). System service flows, maximum effective concentrations, and filter and chemical media are listed as reported by the manufacturer, and have not been verified or tested.

3.2.1 Municipal Iron Treatment Systems

With the exception of polyphosphate injection, all municipal iron treatment systems utilize some form of oxidation, followed by settling and/or filtration. Precipitates are removed by backwashing. Chemical oxidants used are chlorine or potassium permanganate. Filter media employed are often proprietary mixtures, which commonly include manganese greensand. More recently, air-oxidation filter systems have become more common.

Major factors for municipalities include both initial and operating expense. Chemical costs can contribute substantially to operating costs, and permanganate costs are typically substantially higher than for chlorine. Aeration systems have

Table 4. Representative list of currently-available (1987) iron-treatment equipment for residential or municipal use. No products in this list have been tested or verified to be effective in this study; their inclusion here is only to representative products typical of their category, for which technical information is available. No endorsement is stated or implied.

PRODUCT NAME	TREATMENT PRINCIPLE	FLOW CAP. (GPM)	MANU. MAX. IRON REMOVAL CAP. (mg/L)	MUNI-PAL OR RESI-DENT-IAL	OXIDANT	FILTER MEDIA
MacClean	oxidation/ filtration	4-1250	--	M,R	air	***
Kinetico	oxidation/ filtraiton	3-6	10-15	R	KMnO3	manganese greensand
Watersoft Provectr I	oxidation/ filtration	3-9	20	R	air	*** (Multi-Blend)
Filtronics Electromedia I	oxidation/ filtration	125-4500	--	M	chlorine gas	***
Aquatrol Ferr-X	oxidation filtration	25-, 2500	15	M	air	***
Kinetico Rust-Plus	ion exchange	3-6	50	R	none	***
Aqua-Mag	seques-tration	N/A	4	M,R	none	none
Auto-Trol Land-O-Matic	down-well chlorina-tion	N/A	--	R	Na-hypo-chlorite pellets	none

*** indicates proprietary mixture; composition unavailable

almost no chemical expense, except for disinfectant chlorine. Use of chlorine has the added advantage of helping to control iron bacteria in the distribution system, as well as to assist oxidation.

Table 5 lists the 9 currently-operating iron-treatment systems in Montana (Montana DHES, 1987). For comparison, there are approximately 200 municipal systems in Saskatchewan that have iron-or manganese-removal systems (Saskatchewan Environment, 1984) and an estimated 52 in North Dakota (North Dakota Department of Health, written communication, 1986).

3.2.2 Domestic Iron Systems

Iron water-quality problems are more challenging for rural households than for towns, which have more discretion in locating water wells which produce low-iron water. Water chemistry, iron load, and the chemical state of iron (dissolved, colloidal, complexed) is highly variable in domestic wells. In addition, there is a confusing abundance of residential iron treatment alternatives available to the rural wellowner. As indicated by the broad variety of iron-treatment techniques discussed above, various treatment approaches are not equally successful with all waters.

The main obstacle Montanans face in selecting an effective iron-treatment technique is lack of information, both regarding treatment alternatives and the special treatment needs of their own water supplies. Steps one can take to obtain useful information include:

- To work with an experienced, technically capable water-conditioning specialist in selecting and installing an iron-removal system

- To have a representative water sample collected and analyzed for gross chemistry and iron and manganese load

- To avoid lower cost non-oxidative filters (often sold as "water purifiers"), unless there is good evidence that such a system will work on the water supply in question.

Finally, there are new aeration-type product designs (such as the MacClean's or Watersoft residential units) that use no chemicals and are designed as low-maintenance systems. While there has been favorable response to these products in other areas of the country, relatively few of such units are in use in Montana. Some form of testing and evaluation is needed to assess if these economical, reportedly maintenance-free systems can handle the range of Montana iron quality problems. If successful, economical units of this type may even be applicable to small municipal systems.

Table 5. Municipal water systems in Montana with operational iron treatment or removal systems (besides chlorination). Source: Montana Department of Health and Environmental Sciences, 1986.

TOWN	OXIDANT	IRON REMOVAL OR TREATMENT
Antelope	permanganate	pressure filtration
Dutton	polyphosphate	sequestration
Glasgow	none(aeration)	gravity filtration; softening
Grass Range	permanganate	pressure filtration
Poplar	polyphosphate	sequestration
Sidney	permanganate	pressure filtration
Stanford	permanganate	pressure filtration
Vaughn	polyphosphate	sequestration
Wolf Point	permanganate	gravity filtration

4. Iron Bacterial Problems in Montana Groundwater

4.1 Iron Bacteria: The Hidden Hazard

Iron bacterial problems were first recognized in water wells and distribution systems at the turn of the century. However, only in the last 10-15 years has the problem been the focus of research by microbiologists, hydrogeologists, and engineers. Even today, the occurrence of iron bacteria and the problems they cause are still widely misunderstood or not known by most water users.

Excellent comprehensive literature reviews on the subject have been presented in recent years (Cullimore, 1981; Smith and Tuovinen, 1985; Hackett and Lehr, 1985). Rather than recount these syntheses, a brief description of the nature of typical bacterial problems is included here.

"Iron bacteria" is the term loosely applied to a number of genera of water-borne bacteria which not only are tolerant of, but thrive in, water having elevated iron concentrations. Water of at least 0.2 mg/L iron is required for their survival; some may actually utilize energy from the biologically-assisted oxidation of ferrous iron, although most simply incorporate chemically-oxidized iron precipitates into their structure. The more common iron bacterial groups are stalked forms (Gallionella); filamentous, often sheathed forms (Crenothrix, Leptothrix); and single-celled, in some cases motile forms (Siderocapsa, Ochrobrium) (Figure 4). The different families have slightly different environmental preferences in terms of pH, oxidation level, and nutrients, although naturally-occuring infestations normally include several species. All are dormant at temperatures below about 40o F; grow slowly at normal groundwater temperatures (45o to 60o); and grow more rapidly at higher temperatures, up to temperatures of about 150o F, above which they are killed.

Iron bacteria are commonly found in natural soils and waters. Well infestations are generally believed to be introduced by drilling or pumping equipment, although they can survive and spread within an aquifer. The bacteria thrive in the well environment where there can be a high level of oxidation, suitable substrate for growth (well casing and pump), a heat source (the pump motor), and a steady influx of fresh nutrients via groundwater entering the well. Infestations normally begin at the well intake and spread to the distribution system and the aquifer outside the wellbore. Most species have a slimy, mucaceous sheath around exposed growth surfaces which enables them to sorb firmly on substrate material and to resist attack from many chemicals and disinfectants. As the bacteria grow, they incorporate hydroxide precipitates into their sheaths, giving them a reddish or pinkish hue. The bacteria themselves are soft and slimy in contrast to the hard natural iron precipitates. The bacteria are generally not thought to represent a direct health hazard, although their proliferation may be associated with or support other species of bacteria or

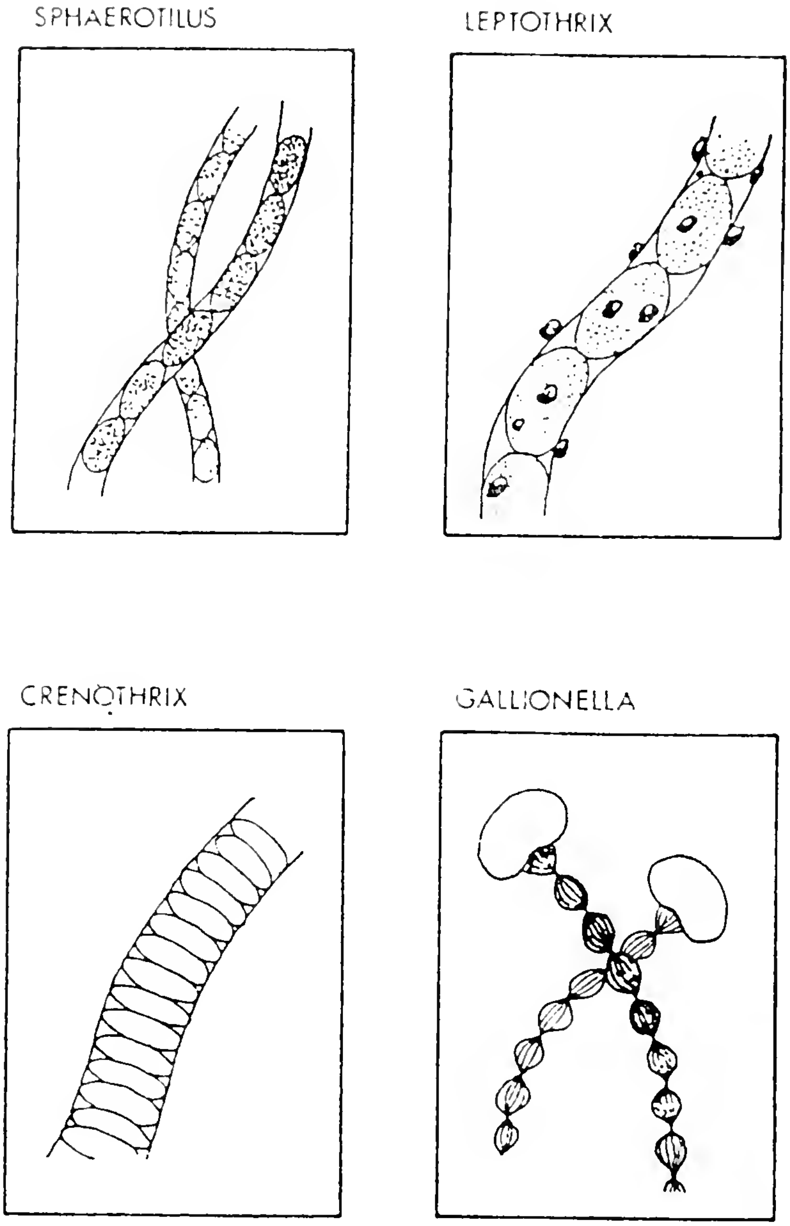

Figure 4. Morphological sketches of four common genera of iron bacteria found in water wells. Sphaerotilus (A), Leptothrix (B), and Crenothrix (C) are filamentous, sheathed forms; Gallionella (D) is a stalked form, marked by its characteristic bean-shaped cell. Single celled forms, such as Siderocapsa, are not shown here. From Cullimore, 1981.

viruses that do. However, they can act to plug off the pump or well intake with their own mass and with iron oxide products they incorporate. If natural iron concentrations are high, the plugging can be accompanied by cementation and encrustation of iron. At advanced stages of infestation, corrosive sulfate-reducing bacteria can co-inhabit the well, causing further damage to the well casing. Bacterial corrosion is invariably linked to galvanic corrosion processes, both of which cause localized encrustation of solid iron deposits.

4.2 Domestic Wells

Residential wells are commonly of low yield (<10 gpm) and of much less careful well completion than municipal wells. It is therefore harder to notice exactly when a domestic well starts to become plugged. The first noticeable distress signal in a low yield well is often the pump or well "sucking air" and losing yield.

The infestation of a water well by iron bacteria follows a series of phases, which can take from several months up to ten years to complete. In the early phase, the bacteria population builds in the well and pump intake vicinity; little indication of their presence is apparent at the surface or in the quality of water from the well. As well efficiency is decreased by plugging, the pumping water level in the well gradually falls, and more oxygen is allowed to enter the well, encouraging bacterial growth. At this point, water pumped from the well will be discolored, may carry clumps of bacterial matter and iron precipitates, and may have a foul odor. Finally, the pumping water level reaches the pump intake and the well begins to "suck air", further encouraging bacterial plugging; at this point, the well will have to be either reclaimed or abandoned.

Currently, no simple field identification technique exists until the problem is sufficiently advanced to cause visible discharges of bacterial matter or changes in water color. However, the iron bacterial problem is likely very extensive, and may be present in most wells with elevated (more than 0.5 mg/L) iron concentrations. In contrast, few well owners are aware of or regularly treat their wells for bacteria as a maintenance procedure, although a number may have replaced a water well or two after it "went bad". Iron bacteria are one of the most common unidentified causes of such well failure.

4.3 Municipal Wells

Municipal wells are most susceptible to economic damage from iron bacteria due to their high cost (from $5,000- $50,000) relative to domestic wells. Whereas there have been few positive identifications of iron bacteria in Montana town wells, case histories suggest these bacteria are common and may reduce the useful life of many high-yield municipal wells to as few as ten years.

The municipal well supply in Plentywood currently has a capacity of about 500 gpm. There are 11 wells in the system, two of which were abandoned "years ago" because they "dried up". Discharge from another well, drilled in 1957, was reduced to only 20 gpm by 1983, prompting a costly (and unsuccessful) chemical rehabilitation effort by a well service contractor. The eight remaining wells -- 3 drilled in 1957, 2 in 1965, 2 in 1982, and 1 in 1986 -- currently supply the system. The pre-1960 wells are all producing 50% or less of their estimated original yield, but have, to date, never been shock-chlorinated. The 1965 wells have indicated substantial decline in yield over the last 4 years, and now yield 50-75% of their original capacity. The newer wells are still producing up to their original performance. In addition, there are at least 4 older, pre-1950 wells for which there are poor records, but which probably were abandoned years ago.

Table 6 shows some statistics for three municipalities with high-iron groundwater supplies. The experience in these towns all indicate that:

1. Most wells with elevated iron concentrations show a gradual decrease in yield with time, in many cases resulting in well failure

2. Efforts to rehabilitate failing wells in advanced stages are generally costly and not successful

3. New wells, redrilled to replace failed ones, commonly develop similar problems as the old wells

Positive diagnoses of these well failure problems have not been made, but most are ascribed to either iron bacterial plugging, cementation with inorganic iron deposits, galvanic corrosion of well intakes, or, most likely, a combination of these.

4.4 Well Rehabilitation

Once a severe bacterial well infestation becomes established, experience shows it is almost impossible to completely eliminate it. Rehabilitation efforts are often successful for short periods, but because all bacteria surrounding the well bore are not killed, they soon grow and recover their earlier population. However, an infestation treated early and on a regular basis thereafter can almost always be controlled. The best treatment for iron bacterial problems is regular, preventive well disinfection. This prevents buildup of bacteria before they reach plugging levels. For wellowners with iron-rich well water, it would be advisable to treat for iron bacteria before problems start, even if there is no obvious evidence of their presence. The most common technique is chemical disinfection using a strong chlorine solution. The procedure for routine well chlorination is simple, and, with care, can be performed without assistance from a well service outfit (Appendix A).

Table 6. Well-field history and yield declines in three eastern Montana municipal groundwater supplies. Sources: municipal water commissioners in Sidney and Plentywood; city engineer in Wolf Point.

TOWN	TOTAL WELLS	NO. OF WELLS ACTIVE	NO. OF WELLS ABANDONED	NO. OF WELLS WITH >50% YIELD LOSS	APPROX. YEARS TO LOSE YIELD	APPROX. IRON CONCENTRATION (mg/L)
Plentywood	11	8	3	3	15-20	0.15-3.0
Sidney	10	7	1	3	?	0.2-3.0
Wolf Point	9	3	1	6	10-15	0.8-4.5

From an economic standpoint, the cost of domestic well replacement is often comparable to and, in some cases, less than rehabilitation using a water well outfit. Preventive disinfection is often the well owners only weapon against iron bacteria. The shock-chlorination procedure in Appendix A is a good preventive approach when done conscientiously once or twice a year.

Another preventive technique is to frequently drop HTH (calcium hypochlonite) pellets to the bottom of the well. One commercially available device, the "Land-O-Matic", is a wellhead-mounted HTH pellet deliverer, designed for automatically-timed regular well chlorination. Such low-level chlorination does not restrict growth of bacteria outside the well bore.

Residential landowners need information regarding iron bacteria. Lack of awareness of the problem is one of the most serious aspects, as the problem can be controlled with preventive measures.

Municipal wells represent a more sizable investment than residential wells, and therefore are more likely candidates for rehabilitation. On the hand, water-system managers in Plentywood, Wolf Point, and Sidney have hired contractors to rehabilitate inefficient wells, often in advanced stages of encrustation or plugging. The cost of such treatment, using acid or chlorine solutions, is typically from $2,000 - $6,000. These efforts have not been highly successful, and were followed by drilling of new wells. Several Montana towns are currently initiating preventive well-maintenance programs to treat for iron, iron bacteria, and scale buildups before large well efficiency losses are noticed.

For municipal as well as for residential wells, regular preventive well disinfection procedures may be more successful in dealing with iron bacterial problems than after-the-fact rehabilitation efforts.

5. Summary

Currently-available water quality data indicate that groundwater throughout the state is prone to iron problems. The most susceptible aquifers are glacial and alluvial deposits in the central and eastern parts of the state; also susceptible are the Fort Union Formation and Kootenai Formation aquifiers. Least susceptible of all are Paleozoic aquifers of the Madison Group, Amsden Formation, Big Snowy Group and the Fox Hills - Hell Creek formations.

Sampling for iron in water poses special sample preservation problems due to the speed with which iron precipitates from groundwater at the surface. It is recommended that in the future, groundwater samples should have both filtered acidified and raw acidified samples collected for domestic and research wells. This will ensure that the chemical analysis will reflect water chemistry at the source, without removal of iron by filtration. It will also assist in integrity of data with respect to other trace metals, which can be efficiently scavenged and removed from the water by iron oxide precipitation.

Iron problems are extensive in municipal and domestic wells throughout Montana. Nonetheless, there has been more experience with and attention to iron treatment and iron bacterial problems in neighboring states, particularly with respect to municipal systems. In part, this is due to a greater severity of these problems in neighboring states. However, nationwide awareness of iron problems and development of new treatment techniques is expanding. To take advantage of these trends, Montana needs research in areas such as the following:

- selection and verification of iron removal methodologies and specific designs for small towns

- characterization of iron bacterial growths in problem wells, for iron as well as anoxic bacteria

- an inexpensive field culturing technique for determining bacterial infestation levels in wells before they reach problem proportions

Information dissemination is an inexpensive, practical approach to control of the iron bacterial problem.

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APPENDIX

PREVENTIVE TREATMENT FOR IRON BACTERIA CONTROL IN RESIDENTIAL WELLS

1. Determine the equilibrium (non-pumping, or static) water level in the well. Subsract this depth from the well depth. For a 6-inch well, add a quart of common laundry bleach and 30 gallons of water per 20 feet of water height in the well. For a 4-inch well, add half this amount. If possible, introduce the bleach to the bottom of the well using a rubber hose.

2. "Surge" the well for 30-60 minutes, by starting and stopping the pump intermittently. If you do not have a check valve installed on your pump, be very careful not to restart the pump too soon after stopping it, or you could damage the pump motor. Recirculate any clean water pumped out down the casing; discharge badly fouled water to waste.

3. Add clean water (the same amount you added before) and allow the well to stand without pumping for 12-24 hours.

4. Pump well to waste, surging again occasionally until the water is clear and the chlorine smell is gone. Pump out at least three times the volume of water added to the well. Don't pump discharge onto lawn or garden or into cistern; chlorine in strong concentration will kill lawns, plants, and microorganisms.